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Final Technical Report: Continued Development of the AF/SGR "Tricorder" Program for Homeland Security, Military, Public Health, and Medical Operations

Final Technical Report

Reporting Period: 30 September 2009 – 15 May 2012

Prepared for:

DEPARTMENT OF THE AIR FORCE

Office of the Surgeon General

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14. ABSTRACT
The overall purpose of the Continued development of the AF/SGR "Tricorder" Program for Homeland Security, Military, Public health, and Medical Operation is to develop a remote sensing device capable of detecting directed energy (DE) threats to medical personnel, combat support personnel, and civilians. Capabilities will include wireless transmission of medically relevant threat information to military agencies and will be stored in databases for analysis and mitigation.

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iii. Abstract

Laser exposures pose an increasing threat to many types of operations; advanced sensing and communication capabilities may reduce unexpected exposures and increase operators' health and safety. The overall purpose of the "Continued Development of the AF/SGR 'Tricorder' Program for Homeland Security, Military, Public Health, and Medical Operations" is to develop a remote sensing device capable of detecting directed energy (DE) threats to medical personnel, combat support personnel, and civilians. This feasibility study explore the development of the device as well as wireless transmission strategies to delivery medically relevant threat information to military agencies and will be stored in databases for analysis and mitigation.

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A. Chapter 1- Active DE Detection

1. Summary

SSI investigated and demonstrated hardware architecture for detecting and locating optical devices used for targeting or operating directed energy threats to personnel. The design makes use of a pulsed diode laser operating at 940 nm and a custom gated camera which is controlled to integrate energy only during the laser pulse firing. The gated camera ensures that the camera does not miss pulses because of a mismatch between the integration time and laser firing. Also, the gating minimizes the background energy thus enhances the contrast of the retro-reflected signals. A breadboard instrument was fabricated to prove the concept and a design was carried out for a handheld system.

2. Introduction

Sensing Strategies, Inc. (SSI) investigated technologies for detecting optics of interest as part of the “Continued Development of the AF/SGR ‘Tricorder’ Program for Homeland Security, Military, Public Health, and Medical Operations” program. The goal of this effort was to design a handheld device into the suite of Tricorder components, although the scope of the effort is limited to analytical and experimental demonstrations, not the actual fabrication. The “Active Tricorder” (AT) was developed to expand the threat detection and warning capabilities of forward deployed medical personnel concerned with a wide range of health risks and threats to US personnel. A wide range of government programs have previously investigated the use of retro-reflections for detecting optics. This effort was carried out to develop a device suitable for use by medical personnel while carrying out their missions and for incorporating the data from the device into data dissemination streams.

Figure 1 shows an example of a retro-reflected signal from a field test deployment for the Tricorder program in December 2009. The target is ½ inch diameter corner cube located approximately 1 km from the laser source. A low power HeNe laser was used to illuminate the cube and the return beam verified the laser pointing for testing other sensors. The picture illustrates the concept of the AT and shows how even low power lasers can be used for optic detection.

Figure 1: Retro-Reflection from 1 km at Fort AP Hill

The overall objective of the effort was to provide a technical design, suitable for fabrication; that could enhance medical personnel capability to detect optical target (binoculars, surveillance systems, etc.) which could be an early indication of potential hazards to US personnel. Specific technical objectives included:

1. The non-visible laser beam should be eye safe at its aperture.
2. The beam emitted should be eye safe to personnel viewing the beam with binoculars at a distance of 250 meters.
3. The system should operate on batteries and have minimal size, weight and power impact.
4. The detection range is anticipated to be between 500m and 1000m.

3. Methods, Assumptions and Procedures

The AT system concept, illustrated in *Figure 2*, involves directing a low power laser beam at locations suspected of having optical systems of interest. The retro-reflection (cat's-eye return) from optical systems stands out in contrast relative to diffusely reflecting items which makes an imaging system suitable for identifying the location of the return. It is the purpose of this effort to evaluate candidate approaches for making a low power, portable system capable of taking advantage of this phenomenon.

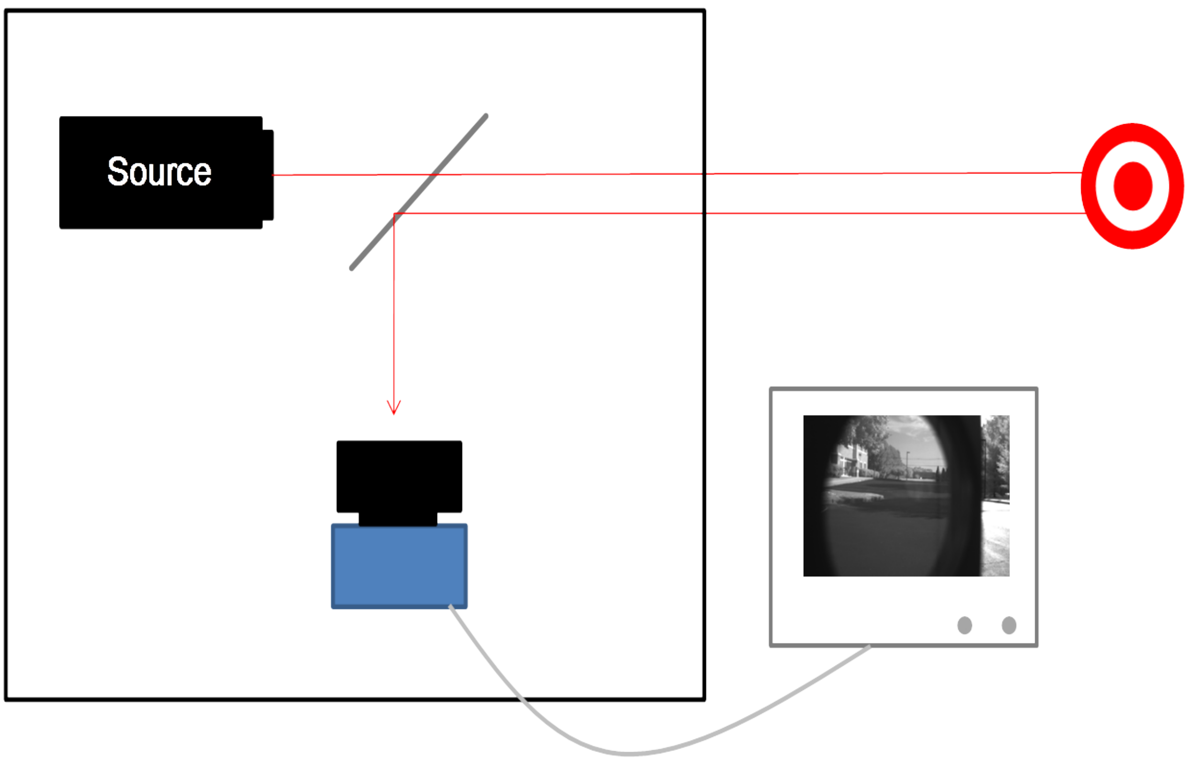

Figure 2: Simplistic Layout for Active Tricorder System

Three designs were considered for the AT analysis, all of which use imaging detectors for sensing the return beam. Each of the three approaches has a rationale for the technologies selected. The first is a CW 780 diode laser used with a silicon camera for detecting the return beam. The beam has high average power so it needs to be expanded to be eye safe at the aperture. One disadvantage of this source is it needs to be thermoelectrically cooled to stabilize the laser wavelength which adds to the power and size requirements of the device.

A pulsed laser approach is also considered as a design option using a 940 nm laser and a silicon camera. The 940 nm laser is preferred over the 904 nm laser used for the model validation since it operates slightly outside of the bandpass of night vision goggles. This would make the source less likely to be noticed by an adversary who might also be using night vision equipment. However, the 940 nm wavelength still falls in the silicon bandpass, so low cost silicon cameras can be used in the system.

The third approach uses a 1.55 micron laser characteristic of “eye safe” laser rangefinders. The MPE at this wavelength is many orders of magnitude higher than at the 940 or 780 nm wavelengths. Therefore, higher laser pulse energies can be used in a system without concern for eye hazardous operation. However, the goal of developing a battery operated, handheld device limits the achievable output power well below any concerns for eye safety since diode lasers must be used. If the source could be vehicle borne and have access to higher electrical power levels, this wavelength would offer an advantage by using much higher laser pulse energy produced by a q-switched solid state laser without concern for eye safety.

Table 1 summarizes the source characteristics for the three different approaches, and *Table 2* presents the parameters used for modeling the two camera systems. Data from vendor specifications sheets was used to fill in the parameters for representative sources and detectors.

Table 1: Source Characteristics

Source Parameters	Value for pulsed 940 nm laser	Value for 780 nm CW laser	Values for 1.55 micron laser
Wavelength (nm)	940	780	1550
Pulsewidth (PW in ns)	1000	CW	200
PRF (Hz)	5000	N/A	2000
Pulse Energy (mJ/pulse), (W)	5.00E-02	.05 (W)	9.60E-03
Laser Diameter @ aperture (cm)	7.5	5	2.5
Laser Divergence (mrad)	3	3	3

Table 2: Camera and Scenario Parameters for Modeling Calculations

Parameter	Silicon Array	InGaAs Array
Optical System Distance (m)	1000	1000
Atmospheric Extinction Coefficient (1/km)	.05	.05
Camera Horizontal FOV (degrees)	10	10
# Horizontal Camera Pixels	640	640
Camera Spectral Width (dλ)	25	25
Camera QE	.5	.7
Camera Frame Rate (Hz)	60	60
Camera Aperture (cm)	5	5
Camera Full Well (# Electrons)	2E+05	7.5E+04
Camera Noise (electrons)	85	70
Optical Throughput	.6	.6
Background Spectral Radiance (W/cm^2/sr/um)	1.00E-02	2.00E-03

One key objective of the AT is to be eye safe at the system's aperture as well as for someone viewing the beam with binoculars at 500 m. Irradiance calculations were made at both the Tricorder aperture and at a 500 m distance to compare with the eye safe levels. For the Tricorder aperture case, a 0.25 second exposure is assumed. This is taken to be representative of an incidental exposure when handling the device. The longer exposure of 10 seconds is used for the observer at a distance who would be more likely to be staring at the beam for a longer period of time.

The maximum permissible exposures for the three proposed sources were computed using equations from the ANSI Z136.1-2000 *American National Standard for Safe Use of Lasers*.

Table 3 presents values for ¼ second (CW) and single pulse exposures as well as ten second exposures. It is seen that the 1.5 micron laser has roughly a six order of magnitude advantage over the 940 nm source in terms of allowable fluence exposure to the human eye. It is because of this difference that the 1.5 micron case is considered in this analysis.

Table 3: MPE Values for Sources

Source Parameters	MPE Value
MPE (0.25s CW, 780 nm)	3.68E-03 W/cm2
MPE (10s, 780 nm)	1.45E-03 W/cm2
MPE (1 pulse, 940 nm)	1.51E-06 J/cm2
MPE (10s, 940 nm)	1.01E-07 J/cm2
MPE (1 pulse, 1550 nm)	1.00 J/cm2
MPE (10s, 1550 nm)	2.85E-01 J/cm2

Table 4 presents the design calculations for the three different approaches applied to detecting optical systems at a 1000 meter range. The two pulsed source designs are comparable in performance with a slight edge to the 940 nm laser wavelength. Their performance is better than the CW laser since the pulse energy is concentrated in a much shorter time and is captured in the integration window which is short to keep the camera from saturating on background radiation. Table 5 shows the same calculation for a dusk background condition (50× lower background) and the contrast and signal to noise ratio for the CW laser is improved and actually exceeds that of the 1550 nm source. The 940 case improved as well due to the high pulse repetition frequency of the laser.

Table 4: Model Calculation Results for Optical System Detection (Daytime)

Parameters	Values for Pulsed Laser	Values for CW Laser	Values for Pulsed Laser
Source Wavelength (nm)	940	780	1550
Aided Viewing Cross Section (cm^2/sr)	2.50E+05	2.50E+05	2.50E+05
Camera Integration Time (ms)	0.15	0.15	0.10
Background Electrons	1.34E+05	1.11E+05	4.11E+04
Noise Total	3.75E+02	3.44E+02	2.20E+02
Laser Electrons	9.66E+04	1.20E+04	2.14E+04
SNR	2.57E+02	3.50E+01	9.73E+01
Contrast	72.3%	10.8%	52.1

Table 5: Model Calculation Results for Optical System Detection (Dusk)

Parameters	Values for Pulsed Laser	Values for CW Laser	Values for Pulsed Laser
Source Wavelength (nm)	940	780	1550
Aided Viewing Cross Section (cm^2/sr)	2.50E+05	2.50E+05	2.50E+05
Camera Integration Time (ms)	1.5	1.5	1.0
Background Electrons	2.67E+04	2.22E+04	8.22E+03
Noise Total	1.84E+02	1.71E+02	1.24E+02
Laser Electrons	6.76E+05	1.20E+05	4.28E+04
SNR	3.67E+03	7.01E+02	3.44E+02
Contrast	2530%	542%	521%

The performance calculations indicate that the 940 nm laser diode provides the best performance of the three approaches considered. However, there are two other considerations that reinforce the selection of this approach for further development. First, the CW laser requires a thermo-electric cooler and controller which add significantly to the size, weight and power draw of this design approach. These factors rule out the CW laser since it is our objective to design a handheld instrument that is battery operated.

The disadvantage of the 1.55 micron approach is that the camera used for imaging needs to be made of InGaAs, a material that dramatically increases the cost of the sensor. Since there is no signal to noise advantage with this approach, it is rejected from further consideration. However, it is noted that if the power and size requirements are loosened (e.g., vehicle borne sensor instead of handheld), one could purchase a pulsed, q-switched laser that could significantly extend the detection range. Since a multi-milliJoule pulse could be used and remain eye safe at the aperture, the detection range could be extended further without safety concerns.

4. Results and Discussions

Model Validation Measurements

SSI's model validation activities were primarily aimed at accurately predicting irradiance on an optics system of interest and return irradiance at the Active Tricorder. A pulsed laser was used for these measurements so that optics scatter from the outgoing beam could be separated temporally from the return beam. A calibrated witness sensor was used to measure irradiance at both the optics system of interest as well as the return signal. *Figure 3* presents the basic set-up for the measurements, and *Figure 4* is an oscilloscope trace that shows the outbound and return pulses separated in time.

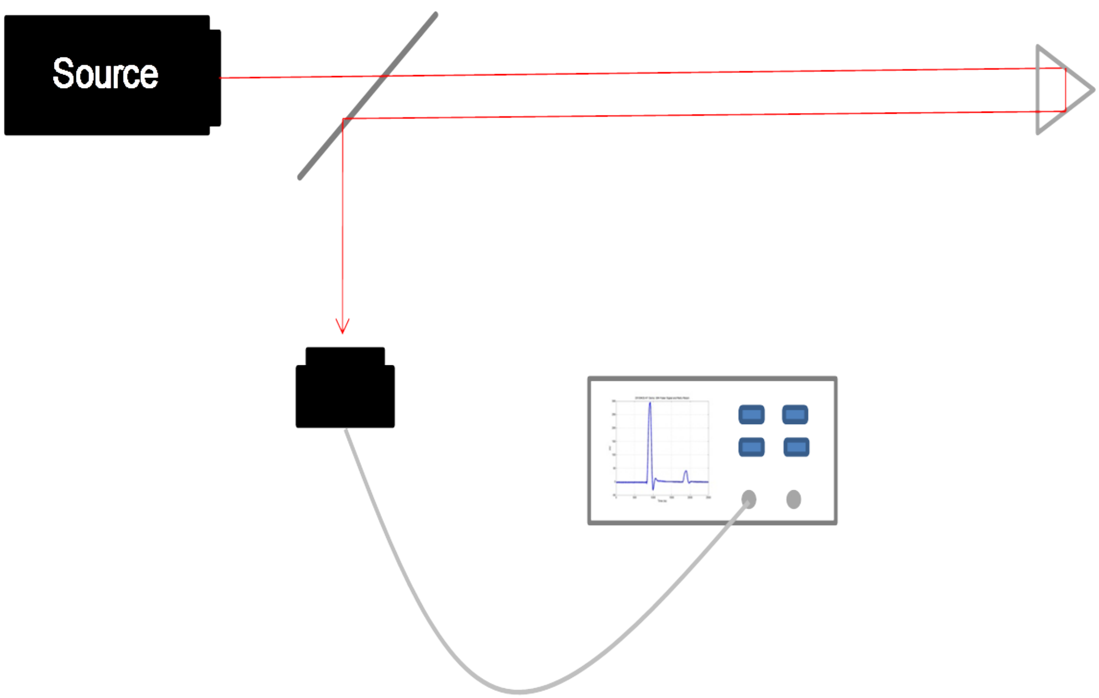

Figure 3: Basic Set-up for AT Model Validation Measurements

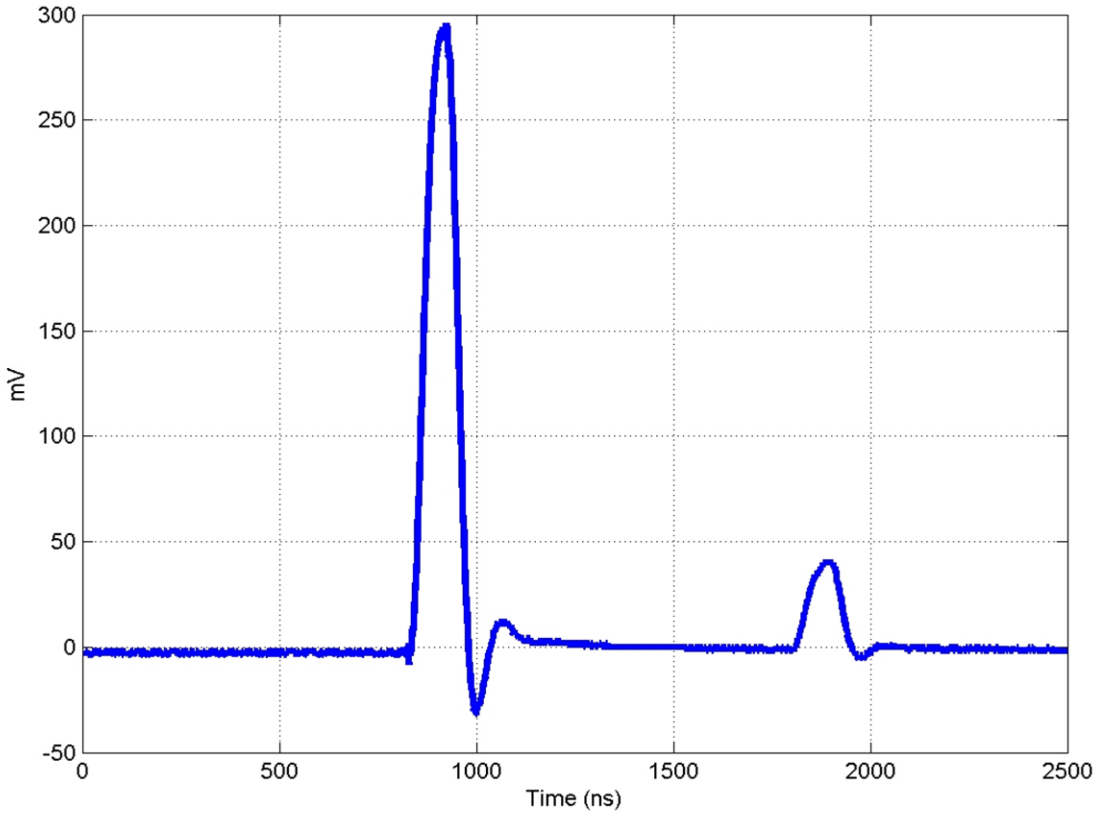

Figure 4: Oscilloscope Trace Depicting the Outbound and Return Pulses Separated in Time

The first step in the modeling process was to ensure predictions of the fluence on an optics system of interest could be made reliably. The laser was a 904 nm diode which was fiber optically coupled to create a circular diverging beam. The output of the fiber was beam expanded and divergence measurements of the resulting beam were made over a distance of 20 meters. Using the measured divergence, the beam diameter and irradiance (W/cm2) at the optics system of interest could be computed as a function of range. A calibrated witness sensor was used to verify the calculated irradiances at distances varying from 25m to 75m. *Table 6* shows the predicted and measured fluences at two distances.

Table 6: Predicted Versus Measured Fluences at the Optics System of Interest

Distance (m)	Predicted Fluence (J/cm^2)	Measured Fluence (J/cm^2)
40.8	2.00E-08	1.95E-08
75.0	5.92E-09	5.23E-09

Having validated the ability to predict laser fluence as a function of range, SSI proceeded to carry out measurements with a variety of optical targets. The first set of measurements was with a commercial ½" diameter corner cube. Next, measurements were made with a person viewing the laser source through binoculars to determine the signal levels of interest to this program. Finally, measurements were made with a new mock optical system fabricated to replicate the optical cross section of the person with binoculars. *Table 2* presents measurements of the returned signal at two laser to optic system distances. After factoring in the optical throughput of the pellicle, the implied cross section of the retro-reflector is 3.33×10^6 cm^2/sr.

Table 7: Predicted Versus Measured Return Fluences from Retro-Reflector

Optic System Distance (m)	Measured Detector Fluence (J/cm^2)
94.5	2.67E-11
118.5	1.30E-11

In addition to having the mock system and various optical targets, SSI obtained an adjustable calibrated optical target system from the Army Center for Countermeasures. The optical cross section characteristics of the COT-L device as a function of setting are shown in *Table 8*.

Table 8 Optical Cross Section Values of COT-L

COT L Monostatic Signature (m2/sr)	
Setting	Value at 950 nm
1	3405
2	2436
3	1772
4	989
5	317
6	287
7	356
8	146
9	82
10	68.6
11	13.8
12	9.9

With the measurement techniques and optical targets defined, SSI assembled a breadboard optical system for testing the AT concept. *Figure 5* shows the breadboard which includes a fiber-optically coupled pulsed 940 nm laser diode and a commercial video camera for capturing the return pulses. A pellicle beam splitter is used to co-align the laser beam with the camera field of view and the laser energy reflecting from the pellicle (orthogonal to the propagation path) is captured by an optical stop. The small diameter of the return beam necessitates that the camera be co-aligned with the outgoing beam which is why the pellicle is used rather than having the camera simply next to the laser. The camera digital output was viewed on a laptop display and recorded in memory. In operation a cover was placed on the breadboard to keep stray light from affecting the camera video.

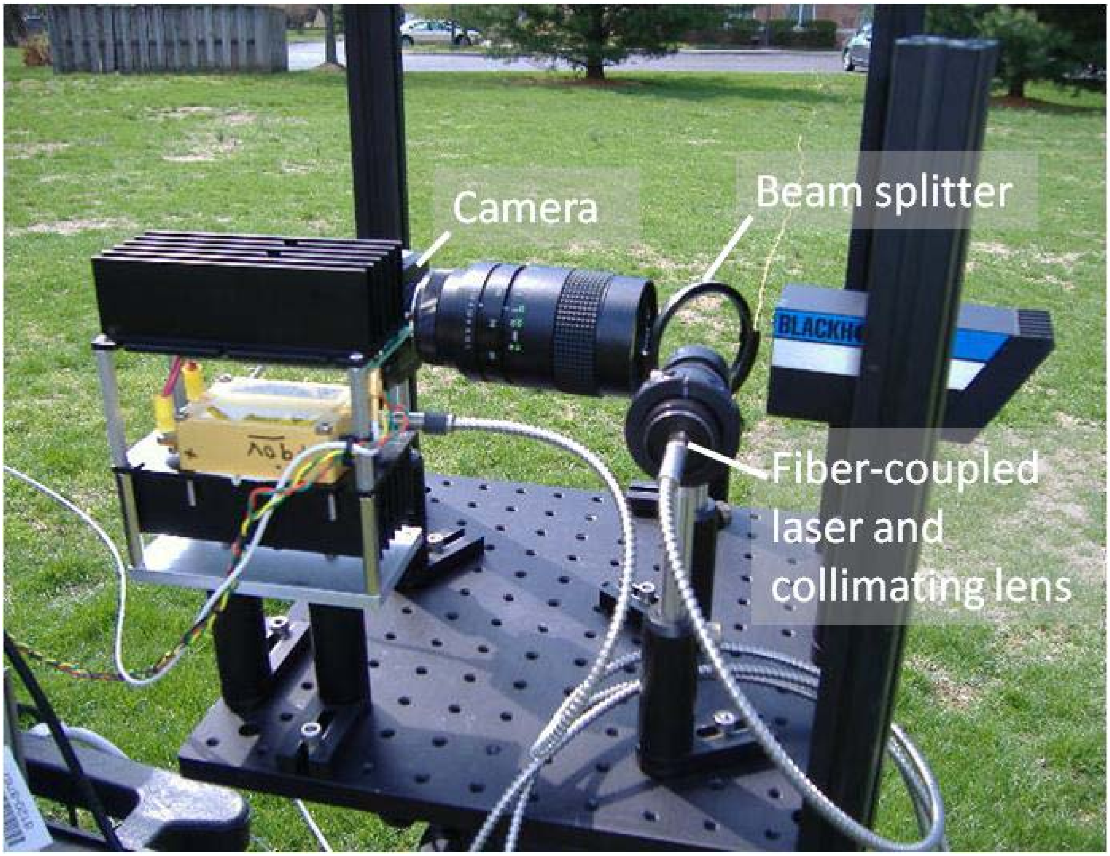

Figure 5: Initial Active Tricorder Optics Breadboard

Figure 6 shows images taken with the AT breadboard. In this scene, the system was approximately 50 meters from the building in the scene. Sample images are taken with a person viewing the AT system through a riflescope (left-hand panel) and a pair of binoculars. Interestingly, the binoculars return was dominated by an internal reticle rather than a return from the viewers' eyes.

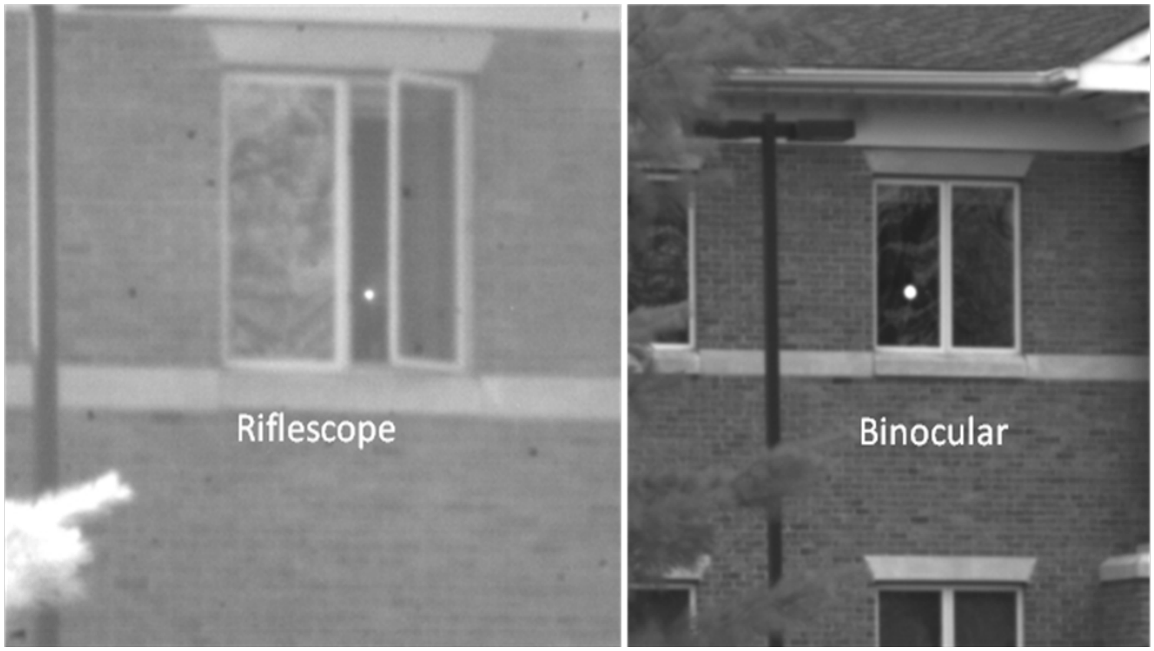

Figure 6: Results of Initial AT Breadboard Measurements

The initial AT breadboard did successfully capture retro-reflection images as seen in *Figure 6* which validates the energy levels required and the overall system approach. However, the use of a commercial camera run independently of the laser made it so the probability of capturing the return signal was relatively low. Since the camera adjusts its integration time to compensate for background variations, it operates at a very low duty cycle in bright background conditions thereby making it unlikely that the integration window will line up with the laser pulse in time. To compensate for data collection purposes, SSI ran the laser at a high laser pulse repetition frequency to capture return signals, but this would be an undesirable approach for an actual system due to power draw and eye safety considerations.

Because of these shortfalls, SSI developed a custom camera for which the camera integration time could be controlled (gated) by an external source and thereby synchronized with the laser firing. A timing circuit was fabricated to fire the laser (pulse duration of 1 microsecond) once per video frame and the camera integration time was restricted to a window slightly larger than the 1 microsecond firing. The 1 microsecond limit was a function of the laser diode which could be damaged by firing for longer durations. With this short integration window, the background scene developed by the camera was minimal thereby greatly enhancing the contrast of the return pulse. Furthermore, the gating ensured that every video frame had a return pulse in it so the laser return was a steady feature in the scene. *Figure 7* shows the breadboard assembled for testing.

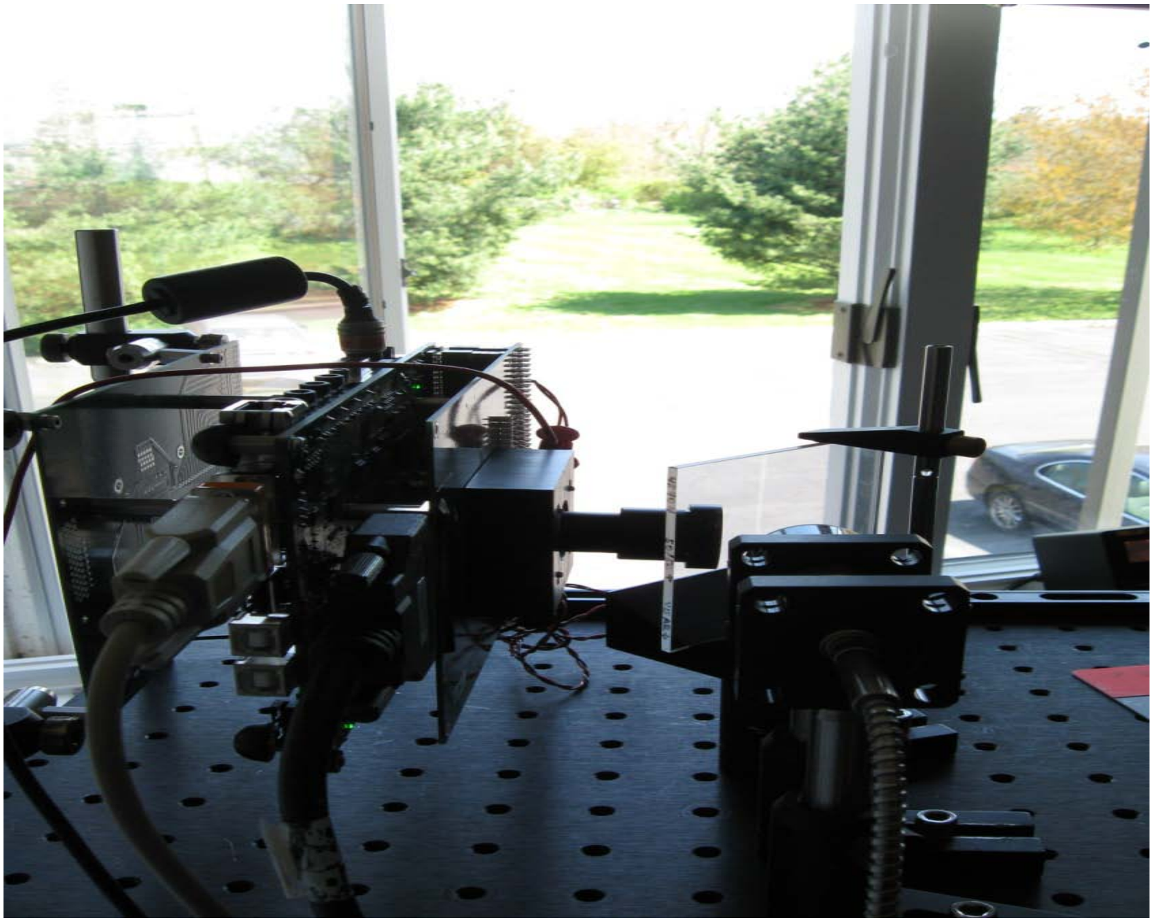

Figure 7: Final AT Breadboard

Figure 8 shows the optics of interest used for the reflection testing and *Figure 9* shows the scene from the perspective of the breadboard instrument. The data collected were taken in these bright sunlit conditions evident in the pictures.

Figure 8: Army COT-L System and Commercial Binoculars Used as Optics of Interest

Figure 9: COT-L System and Binoculars at 85 Meters

Two optics were used to condition the beam from the laser diode since the raw beam from the fiber is too widely diverged to be of use for this application. The fiber was terminated into a collimator which produced a beam of 3.7 mrad (about 0.2 degrees). A second diverging lens was used to expand the divergence to 4.5 degrees which matches the field of view used in the gated camera. In this way, the entire scene is viewed for returns from optics of interest. Using this wide of a divergence will limit the range at which the instrument is effective since the retro-reflected signal will decrease as the fourth power of range between the source and target. Nevertheless, for applications (scanning nearby buildings), the larger field of view can be an advantage by reducing the time required to scan a given area.

Figure 10 shows a sample of data from the in scene in Figure 9 taken with the breadboard system. The two optics of interest are evident in the scene with the binoculars being the brighter signal to the right of the COT-L. In this measurement, the COT-L was in the number 8 setting with a cross section characteristic of the low end of aided viewing. The binoculars created a signal about five times greater than the number 10 setting which was estimated to be near a threshold level. These data were collected at a sensor-to-optic range of approximately 85 m. Extrapolating to a 500 meter range requires a 1000 fold increase in power at the optic of interest to detect the same cross section levels. This increase is close to that achieved by using the beam with the collimator only, but the narrow 0.2 degree beam is difficult to scan a scene with because it is such a small angular sub tense. If detecting targets of that magnitude at the 500 m range is needed, another alternative would be to have a cylindrical optic in the design to project a narrow but tall beam to make scanning more effective. In this approach, a narrow wedge of beam would be scanned over the scene by the observer and optic detection would occur over this narrow window in the scene camera.

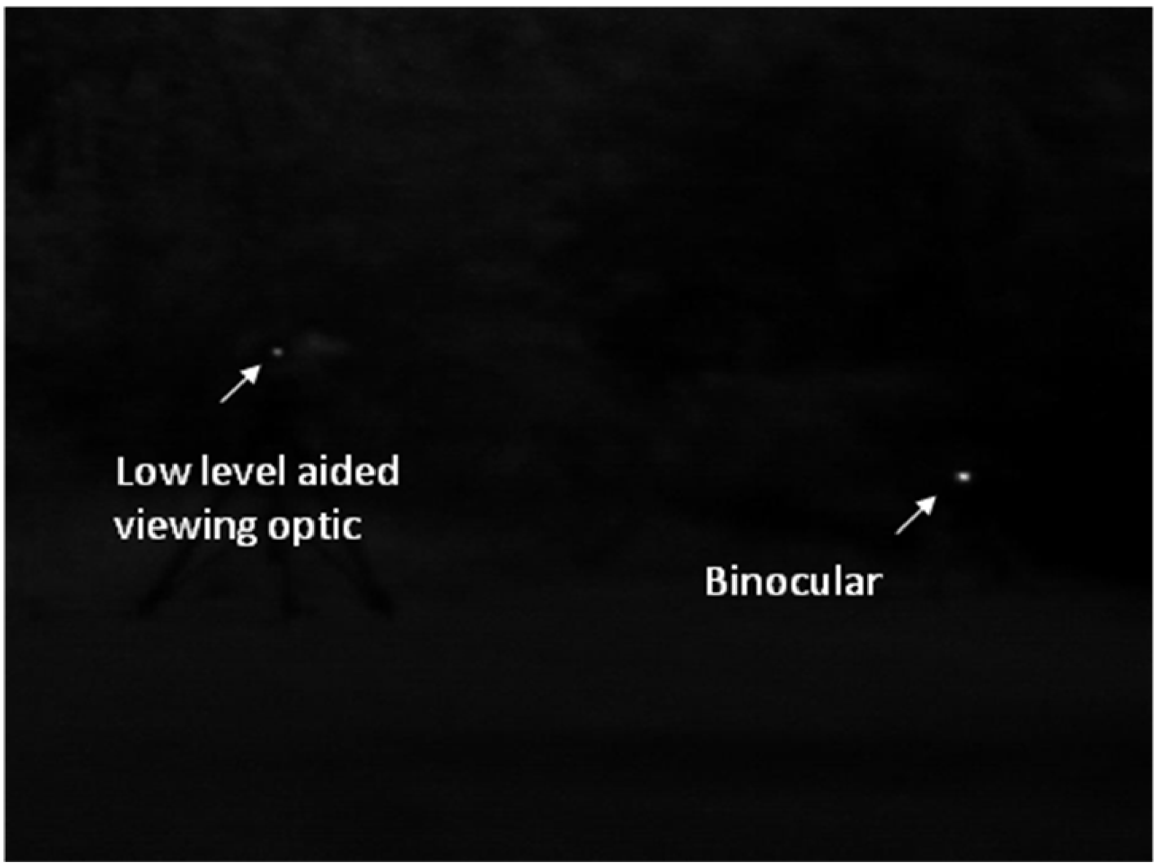

Figure 10: Raw Data Collected at 85 Meters Range

While the data shown in Figure 10 is representative of the raw data in the system, SSI would make the spot detection an automatic process and overlay an icon on the location of the optic of interest in the scene. SSI's has carried out similar data processing algorithms in real-time processing architectures and has developed a system concept based on this approach. The system design integrates the following primary components into a handheld package: the 30W RPMC 930nm fiber optically coupled diode laser described in previous reports; a camera sensor which is gated to match the repetition rate of the laser; a custom circuit board to process the camera images in real time to determine whether a laser return signal is present; and a witness camera to capture a snapshot of the scene when a laser return is detected. In addition, the prototype also incorporates a back panel display, USB port for data retrieval, and a GPS receiver to document time and location of events. The form factor of the design is shown in Figure 11. It measures approximately 8.5" wide by 7.5" long by 3.5" tall, which is similar to the size of a pair of binoculars. The prototype was designed for be able to run off of a battery pack, although for initial testing a wall power supply would be provided to support initial feasibility testing.

Figure 11: Form Factor of Proposed Design

The prototype will automatically search for returns whenever the operator hits a switch on the back panel to enable the laser output. The laser will then run at approximately 10 Hz PRF until the operator shuts it off. Upon detecting a return, the prototype will alert the operator via the back panel display and store the information to internal memory. Data can later be downloaded from the unit via a USB connection.

5. Conclusions

A diode laser based system can be used to detect optics of interest with an inexpensive gated camera used to collect the returned signals. SSI has gone beyond the “paper study” requirements of this contract and fabricated hardware which proved the gated camera approach. The requirements of particular users will need to dictate the final configuration of the system. If the optics of interest is in the range of 500-1000m, the beam will need to be narrow to ensure enough laser power is on the optics to produce a return signal. This will require finer scan control and a longer time to scan a region than if the targets are at shorter range. For example, scanning buildings in an urban environment for targeting optics (riflescopes) could be carried out with a larger field of view as used in our concept demonstration measurements. A handheld device for medical personnel to detect optics of interest is feasible to build based on the technologies demonstrated under this program.

6. List of Symbols, Abbreviations & Acronyms

Symbols

s	seconds
m	meters
cm	centimeters
nm	nanometers
km	kilometers
HeNe	Helium neon
CW	Continuous wave
Ms	Milliseconds
Ns	Nanoseconds
PW	Pulsewidth
Hz	Hertz (cycles per second)
QE	Quantum efficiency
dλ	Spectral width in nanometers
Mrad	Milliradians
mJ	Millijoules
W	Laser power in Watts
PRF	Pulse repetition frequency
sr	Steradiance
MPE	Maximum permissible exposure
J/cm2	Joules per square centimeter
W/cm2	Watts per square centimeter
SNR	Signal to noise ratio
cm2/sr	Square centimeters per steradian
m2/sr	Square meters per steradian
W/cm2/sr/um	Watts per square centimeter per steradian per micron

B. Chapter 2 – Networking & Informatics

1. Summary

The networking and informatics component of the “Continued Development of the AF/SGR ‘Tricorder’ Program for Homeland Security, Military, Public Health, and Medical Operations” program was originally proposed as a literature review and feasibility study. The research goal was to identify a trans-receiver and a network system, or a complete system being developed at the time of this project, that would be capable of transmitting sensor data from a single site to one or many sites. The system was to be capable of accomplishing its mission from any type of terrain, while minimizing the impact from the surrounding environment or current weather.

Beginning with an exploration of user needs (in this case, the nature of the data that needed to be transmitted), the researchers systematically assessed the most precise way to transport the information. The assessment indicated that the optimum network for clarity, strength, and transmittal distance was an ad hoc wireless mesh network, using 802.11n router standard, mobile Internet Protocol version 6, with multiple-in and multiple-out antennae. This configuration would also give the best possible security and quality of service with 802.11e and s protocol standards [1-34].

During the conduct of this research, objectives were modified and the predominant focus shifted more heavily toward methods of transference. Researchers were asked to consider the implications of transitioning from one transmitting point to twenty manned or mobile nodes in a twenty square mile area, transmitting to multiple receiving sites, with undetermined miles between transmitting and receiving points. The investigators, therefore, concentrated on applications of cluster theory [5,13,16-17] together with robot and game theory. These theories allow modules to travel in four clusters of five nodes, with one node in each cluster being designated as the cluster head [22,33-35]. The head becomes the network controller in the unmanned configuration. The controller must handle the awake-sleep transitions in an order to conserve power, collect the data from slave nodes for a single burst transmission, talk to other cluster heads, and determine connections based on security parameters. In a manned configuration, the assigned personnel assume the role of the network controller for all clusters [36,37].

After conversations with Jon Jacoby of the MITRE Corporation, Andrew Wehrli CTR USAF AFMC ESC/XR, and Captain Todd P Myers USAF AFMC ESC/XR, an in-depth investigation of Cursor-on-Target (CoT) began. CoT is a transport agnostic message format that is based on the extensible markup language (XML). XML is a machine-to-machine based language that can converse with or transverse any other machine when coupled with an Internet Protocol address carrying the correct permissions. CoT enables messages to be transported via other assets in the general vectoring sector, share information with other units when given permission, and request assistance using certain formats [38-43]. The information from sensor can be very numerically detailed or compact for transmission, but can trigger small applications at the receiving point. Extensible style language (XSL)[39] can be used at the receiving point with Falcon View to produce a detailed colored map or report in a format that can be understood at glance. These tools lessen the overhead on the network, while enhancing the reporting at the command sites. Flexibility is magnified and remains high for the future.

Consequently, the researchers recommend an 802.11n ad hoc wireless mesh network using 802.11e, s, and x protocol standards with Cursor-on-Target as the basic message format. The transceiver's minimum requirements are ruggedness; 10-hour battery power with solar power back-up capability; 64-gig memory to hold and run the XML and fourth-generation programs required by the Air Force; dual-core processor. Additionally, the transceiver should have the capability to transmit and receive over UMTS/HSPA/HSPA/HSPA+/DC-HSDPA/GSM and EDGE/LTE using 700, 850, 900, 1900, 2100 MHZ. The system must have 802.11g and n protocol and Bluetooth 4.0 capacity.

Future development of this concept will require a research team familiar with networks, programming, and performing in-depth communications research. The team will need to work with the MITRE Corporation, CoT User Group, Air Force, and Public Health. This group will develop the symbolic hierarchy based on Military Standards 2525B to identify the assets and/or materials in the message. The hierarchy must be built, as no codes exist, in any derivative of 2525B describing health-related assets (e.g., sensors, personnel, etc.). The data in transmission should be related to data requested in the USAF Laser Injury Guidebook to address public health and medical concerns.

2. Introduction

The goal of this portion of the “Continued Development of the AF/SGR ‘Tricorder’ Program for Homeland Security, Military, Public Health, and Medical Operations” project was to recommend an all-weather, secure, wireless technique to transmit information from the “Tricorder” sensor system, including the Active Tricorder described in Chapter 1, to any identified public or military health agency. The incident data was to be transferable in a practical and undetectable manner within an urban, rural or a designated tactical environment. The methodologies used to develop the wireless network and the associated broadcast protocols must ensure the authentication of the transmitted data to a yet-to-be-identified host. The host must then re-transmit any gathered data to all identified public health or service agencies, using the appropriate semantics for reinterpretation. The network configuration and transmissions must meet all federal, state, and local regulations and laws and be within civilian and military tactical operational standards.

Various recognized research methods were to be utilized to meet the technical objectives of this study. These methods included: research of applicable literature, discussions with military network engineers, data analysis, mathematical calculations, and protocol-testing using universally recognized networking techniques. Specific civilian and military-technical inputs were not always available, requiring the researchers to make theoretical assumptions based on personal operational and informatics experience. The assumptions were verified through discussions with personnel at the Center for Advance Design, Research and Exploration (CADRE) and are clearly stated throughout this report. This report addresses the individual milestones given in the research contract, together with the course of action that was used to investigate the objective, the method, any assumptions, and calculations. Originally, this feasibility study was proposed as a scientific review of the literature. The object of the program was to determine if a transceiver currently existed that met the requirements of the Air Force Surgeon General’s health and environmental divisions. If there were no transceivers meeting these requirements, the researchers were to explore the potential in the near or foreseeable future of one meeting the generally voiced standards. As the project progressed, the Air Force requested the researchers explore the potential for a network that could transport any type of sensor data now or in the future.

3. Methods, Assumptions and Procedures

Network Specifications

1. **Define Transmittal Distance to Collection Point:**

   Deployment could cover city blocks or rural areas that encompass miles. Based on these assumptions, the researchers performed a literature review investigating the possibility of using the machine-to-machine capabilities of the extensible markup language (XML) to send messages via a passing train or vehicle to a receiving point.

   Additionally, the investigators looked into covert communications as a means to transport data to a 911-collection point within a given municipality. The research indicated it is possible to construct a program procedure that could effectively use the location of cellular towers and railroad tracks, together with the train schedule in a given area, to determine the most efficient way to send the sensitive data to the nearest collection point [39,44,45]. The researchers did not pursue the extremely viable machine-to-machine method of transporting the information to a collection point. This decision was precipitated by the need to conserve battery power under the assumption that the sensors and transmitters will be left unmanned for hours and will have to cycle between sleep mode to conserve power and wake mode to transmit and do system check functions. The covert communications using the cellular tower remains a viable method to transport data and should be reviewed in future if any civilian agencies become interested in the project.

   The researchers undertook this study with some initial assumptions:

   a. The network would always be manned;
   b. It would be within a reasonable distance of a ground-based disseminated collection point;
   c. The Department of Defense Global Information Grid (GIG) remained viable and was in the process of being configured;
   d. The network may require use of line of sight or atmospheric propagation principles with refraction to reach a transfer site or node to pass encrypted data;
   e. Communication satellites would be available; and
   f. The transmitter and sensors would require solar power equipment sufficient to power batteries for the duration of on-site transmission time.

After the release of the initial contract, the researchers learned that the GIG would not be available for the network to use as a connection point during the defined timeframe. Consequently, the researchers performed literature research to identify off-the-shelf sensor transmitters that would meet the still unclear transmittal requirements of SGR. The transmitter would have a proven track record and could be procured by the SGR.

Our efforts produced two efficient and effective transmitters that had been tested and were currently in use: the Man-Portable Interoperable Tactical Operations Center (MITOC) [46] and InteleNet. MITOC is a comprehensive suite of communication products that include inoperable voice, data, radio, and video technologies. The suite can be freestanding or integrated into a traditional mobile command. It was researched and developed through a partnership of three Kentucky Universities and colleges and funded by Homeland Security.

The system has been tested in one of the nation's largest HAZMAT (hazardous material) train derailment in which it provided secure wireless Internet access to ad hoc Emergency Operations Centers for federal, state, and local agencies for over a two-day period [46].

InteleNet is a global smart wireless sensor network that is capable of sending information to a database over the Internet, giving users secure, real-time access to their data integrated with other information sources. InteleNet is a completely protected network, based on open source programming, which can be modified. Users can encrypt their data to enhance the survivability of their information. The collection database can be the users' own designated recovery system detached from Intelesense Technologies' control. The researchers believe this technology and methodology of collecting information on a worldwide basis holds promise and should be explored as a joint project in future.

On September 21, 2010, the researchers met with the Intelligence Surveillance Reconnaissance (ISR) team in Washington D.C. The ISR team discussed an innovation called Remote Access Internet (RAIN) Protocol based on the Internet Protocols and interlaced networking. RAIN would be a viable method for the military, as it would allow a health unit to deploy multiple sensory nodes in various tactical operational areas. Each sensor and its associated transmitter would have its own Internet Protocol or media access control address (MAC) that would be queried by an aircraft when it was time to transmit its data. The Global Cyberspace Integration Center (GCIC) [36] is working on the United States Air Force Airborne Network Management Analysis package, which is an overview of the GCIC's work with other commands on the flying network layer.

The in-flight network would reside just below the satellite network layer. The layer would provide command and control along with centralized data collection control. Colonel Joe Lenertz from CTR USAF ACC AFC2IC/RIN spoke about the GCIC and the need for a flying network and, along with other presenters at the Air Network Conference held during October 2010, stressed the need for network management and control during any operational use of the network. The same theme carried throughout all the reviewed documentation on the Joint Aerial/Airborne Networks; therefore, it is necessary for a totally manned or unmanned sensory network to have at least one controller [36]. A designated secondary controller would provide better continuity to ensure all sensors within the same local network successfully completed their task. The controller would also be responsible for ensuring that the other nodes fulfill their sleep and wake modes to conserve power [47-48].

The researchers were investigating a manned network using 802.11n protocol that can utilize multiple-input/multiple-output (MIMO) antennas, which can have different channels linked to different antennas or one channel linked to both antennas. When one channel is linked to both channels, the antenna receiving the best reception will process the data [23]. The 802.11s protocol enhances connectivity of nodes within an ad hoc mesh wireless network based on profiles, which contain mesh ID. After verification of the profiles is complete, a link between the nodes is established using a secure protocol [5]. As an outcome of this literature review, the researchers strongly recommend SGR adopt this application using the CoT format.

2. Definition of Collection Points for Sensor Data:

A clear definition of collection points for sensor data was never unanimously established. During the initial discussion of the Active Tricorder, there appeared to the researchers a need to store large quantities of unfiltered data; however, as the technology continues to advance and its size decreases, it does not appear to be necessary to store large volumes of data (similar in scope to video feeds). The data collection points originally envisioned in the contract is not necessary. The current geographical locations encompass urban, rural, and remote training within the confines of the United States and its territories. The data will be recorded by the Tricorder device and moved from the Tricorder in a digitized format to the transmitter ready for encoding and transmission.

The researchers, a member of CADRE, and Richard Preston from SSI met in New Jersey on April 21, 2011, to determine the minimal data set that a transmitter would have to collect and transmit. This brainstorming session led to the team's defining the basic data set sent from Active Tricorder or any given sensor as containing at minimum:

1. Sensor ID – unknown size and makeup. This is a shortfall and would need to be determined in the future.
2. Longitude of Acquisition (LON_A) - 8 digits and two decimal places (ex. 09°51'04.53")
3. Latitude of Acquisition (LAT_A) – 8 digits and two decimal places (ex. 53°00'04.53")
4. Direction of Acquisition (D_A) – Alpha (ex. N for North)
5. Longitude of Friendly (LON_F) – 8 digits and two decimal places (ex. 35°51'00.04")
6. Latitude of Friendly (LAT_F) – 8 digits and two decimal places (ex. 00°00'04.00")
7. Direction of Friendly (D_F) – Alpha (ex. W for West)
8. Graphic – Image (pixel size unknown)
9. Time - possibly 6 digits (military time: HHMMSS; ex. 193005)
10. GMT designator (GMT_D) – zone indicator (ex. R = East Standard Time)
11. Date – DDMMYYYY
12. Text – free text format: variable 0 to 250 alpha–numeric characters

If mobility is required, the sensors and transmitters will be mounted within or on top of a military vehicle. Additionally, based on talks with ISR and the airborne network meeting in D.C., the transmitters only have to connect to a receiving/transferring communications network. It would be more efficient to use a straight bidirectional sectional multiple-in/multiple-out antenna within the wireless mesh network's confined coverage area, as distance is not a limiting factor [6,49]. If medical diagnostic data are requested, the field encounter data from the USAF Laser Injury Guidebook should be transformed to structured text for ease in transmission and interpretation.

3. Definition of Existing Network:

In the researchers' telephonic and e-mail inquiries about civilian public health network definitions, they received no specific acknowledgment of the existence of any organized public health networks that collect and store DE or other sensor data at this time. On the other hand, some of the civilian public agencies, including 911 centers, did express an interest in obtaining DE and chemical sensor information. They do not have the funds to construct the necessary infrastructure to collect and control the information. Some states have the Man-Portable Interoperable Tactical Operations Center (MITOC), which provides for satellite facility data transmittal, voice over IP, and sensor integration intertwined with live feed monitoring capabilities. Multi-hop transmittal techniques can be used to send information over the cellular network and ad hoc IP networks in urban and rural areas to 911 centers, where cellular phones are available [45]. Inversely, without a known destination IP node, the message would be terminated, lost or returned if possible.

It has been proven that data can be transmitted covertly within the cellular system; thus, if the emanations of the transmitter and receiver can be minimized, the sensor data can be transmitted over cell lines unnoticed by the company or observers within the area of transmission [44].

The future of the GIG is unknown; consequently, other communication methodologies were researched. ISR Innovation tested an airborne IP method call purple rain, based on the Internet protocols and interlaced networking. Each sensor on this network would probably have its own channel within the network; therefore, it is of no consequence if the sensor and transceiver are unmanned.

This is a viable method for the military and is currently being investigated at the Global Cyberspace Integration Center. At the Airborne Network Layer meeting in Arlington, Virginia, the researchers spoke with Colonel Lenertz from CTR USAF ACC AFC2IC/RIN about protocol to request assistance for network connection from the airborne network layer during the public health exercise or emergency. Col. Lenertz stated that a layer consisting of one aircraft could be assembled and provided for coverage if the request came through channels asking for emergency support or practice support. However, as stated earlier in this report if the network consisted of more than one node (transmitter), one node would have to be a controller. The controller would be manned under the scenarios that the researchers investigated. At the same time, the manned controller could conceivably control multiple nodes using cluster heads as sub-controllers with 802.11s and robot theory [32,35,50]. This theory is still viable, but unnecessary if cursor-on-target accepted as the most strategic effective and efficient communication methodology to pursue.

On September 22, 2011, the researchers spoke with Victor R. ‘Bob’ Garza, Naval Postgraduate School. Mr. Garza shared some information on a satellite feed that could be used in all climates and terrains. The Football BGAN Global Internet Suitcase is an automatic interfacing satellite transmitter. The auto-aligning unit synchronizes with any Bluetooth capable sensor that is within 100 feet of the case and transmits to the satellite for 9 plus hours. A solar collector can enhance the transmitting longevity of the unit. The Football is weatherproof and can be used in temperatures from -15F to 131F [51]. This particular solution would only work as the end node in a network to transmit all the sensor data to the collection point via a satellite uplink, as it is not able to control the network nodes. The Football facilitates data transport, video streaming, and satellite calls.

4. Define Quality of Service Requirements for data transmissions:

The quality of service (QoS) requirements for sensor data transmission could not be determined accurately because the overall communication traffic on the broadcast link was not precisely known, and multiple broadcast links have been considered. As discussions with the Air Force continued over the course of the study, the network continued to evolve. Sharing data between different sensors to help triangulate the source to protect individuals is a new design concept uncovered during December talks with the Air Force. Prior to the introduction of CoT, the researchers thought this new requirement would necessitate more calculations and introduce complications now or in the future. Without CoT, for example, one implication or confounding question needing consideration is when multiple sensors measure the same source of directed energy. Do all the sensors have the same QoS requirements; or, if detection by a second, third, or fourth sensor connected to the network confirms the source of information, does the first sensor have higher priority?

The level of confirmation necessary for the use cases described by the Air Force cannot be the only driver for this decision. If the answer is in the affirmative, then each node must be allowed to transmit immediately, thus flooding the airwaves with multiple packets of information. Normally, the nodes would transmit the data to the next node, which would strip the header and trailer and repackage the packet to cut down on the extraneous bits of information before routing the message to the subsequent node as the message continues to the node for final transmission. The original concept of each node transmitting independently, with the receiving connection being an airborne network consisting of a fly through aircraft as the collector, constrains the transmission time. An immediate timed burst transmission is vital to the collection mission; therefore, part of the QoS decision must be answered by the design of the network. If the network is divided into clusters through the use of the cluster-based protocols like the Low Energy Adaptive Clustering Hierarchy (LEACH) protocol, the QoS will be augmented, while the energy conservation of the mesh network is increased [48,52]. Each cluster would consist of five nodes with only the cluster head/controller conversing with the next cluster. Each cluster head would transmit and control multiple channels with each individual cluster transmitting on one given channel (Fig. 1); thus, transmittal times would decrease while QoS would increase, allowing the controller to transmit the information to the next cluster head or to the collecting network. Once the collection network has received the sensor data, that network would have total control over the QoS and would route the data based on the switches set within MIP v6 and the header and trailer. Each cluster head would be manned and controlled by Pararescue Jumper, health personnel or environmentalist. Protocol would only allow the nodes to converse with a designated node or a neighboring node [5]; however, the controller, which is manned, could talk with other controllers and all nodes, especially when one of the other controllers aborts or malfunctions. The cluster head is also the network manager in accordance with Airborne Network Management Analysis [36].

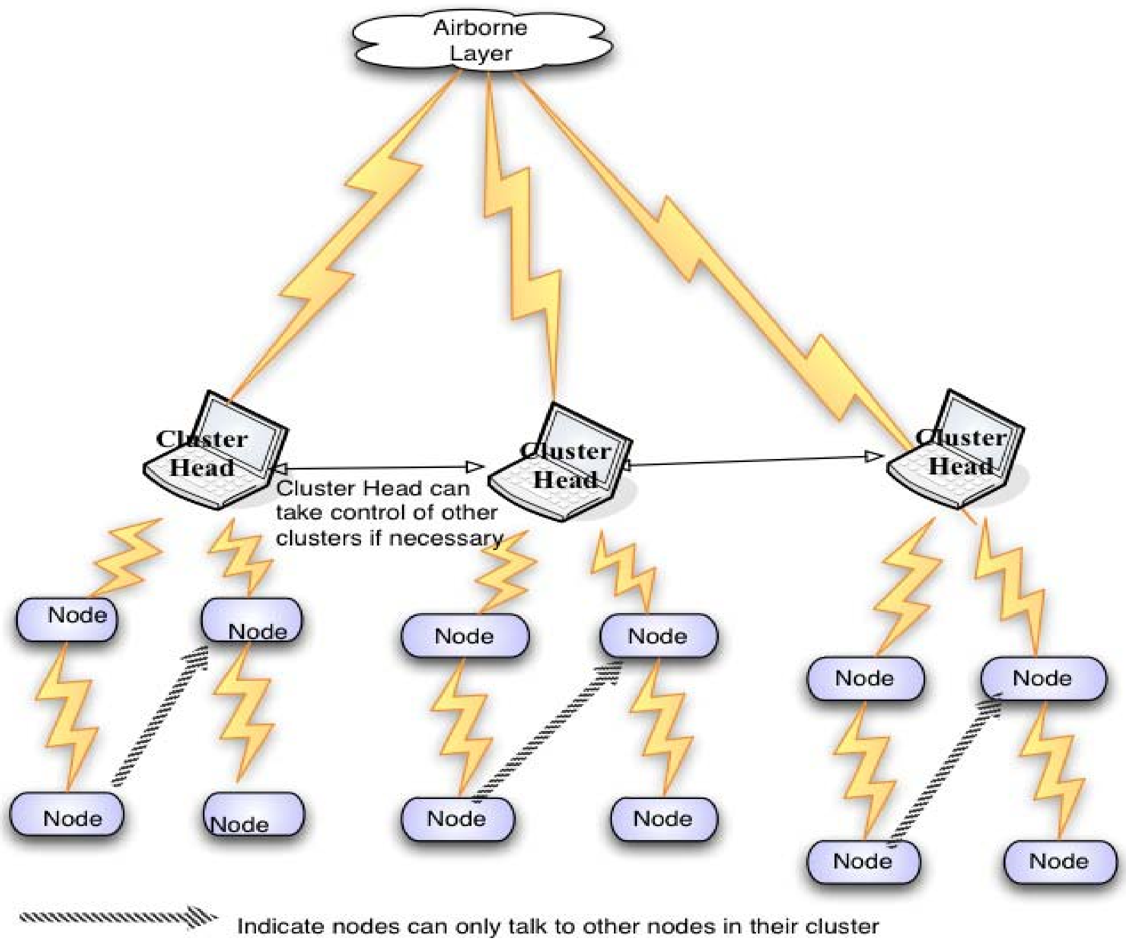

Figure 1: Stevenson, G. [73]. Cluster Configuration. Configuration (Ed.).

Quality of service and the need for a cluster configuration is no longer a concern if cursor-on-target is used. Sensor messages will have their own address, and the message will have a start and stale time. In addition, each message will be transported separately using the most optimum routing.

5. Scope of Future Networks (previously Global Information Grid (GIG)):

In the initial bid, the GIG was the network in the sky. The GIG was unfunded at the commencement of the Active Tricorder project. As mentioned earlier in this report, the researchers attended an airborne network symposium in Arlington, Virginia, and also had a meeting with the ISR team on Remote Access Internet Protocol; both networks operate on the same principle. These networks provide a viable collection point for mesh networks, whether the network is located in a rural, urban, or military operational area.

In January 2011, Maj. Adams clarified the parameters of the wireless transport mechanisms. The transport methodology must be able to connect to and support any given deployable sensor, not just Active Tricorder. The network part of the project, therefore, moved forward based on two scenarios. *Scenario 1* covered the multi-dimensional military situation that encompasses manned modes of operation. *Scenario 2* included civilian deployment in urban and rural locations.

Both scenarios assumed that no global positioning system is available on the sensor, and multiple nodes are deployed. One manned transmitter/receiver must assume control of the pseudo network and become the controller.

In the first scenario, the sensors and the transmitter/receiver can be deployed in a semi-manned scattered configuration. A manned controlled node using 802.11s protocol capabilities could force identity authentication by using route request and route reply. Additionally, the personnel at the manned node could safely ensure the collection of the data from four remote nodes along with the data from their cluster controller site. The transmission is accomplished by using 802.11i & x security protocols and a mesh identification. The controller can oversee the collection, be the network (cluster) controller, and adjust the frequency and/or adjust line-of-sight to overcome some weather interference or the orbit of the airborne network.

Under the second scenario, the sensors would be manned and in a stationary format within an urban or rural area. If the transmitter/receiver were unmanned, it would search for a line of communication either through normal civilian communications, mobile-to-mobile, or be bounced across the atmosphere to a receiver. Testing with an application would determine the optimal mode of operation to determine the possibility of receipt of the message given interference in an area.

Item 1. Local boundary nodes can be determined using global positioning systems (GPS) or triangulation formulas. General latitude and longitude can be received from the Active Tricorder. If GPS information is unavailable, a broadcast message can be used to determine the distance between transmitter/receiver using a transmission-to-receipt acknowledgment time to calculate the locations of the boundary notes. Locations should be included in any returned acknowledgement to enhance the calculation as the clusters move and to decrease broadcast overhead information. Barbeau, Kranakis, and Lambadis [53-54] state that using Medium/Media Access Control (MAC) broadcasts to determine node locations within a mobile ad hoc network (MANET) can lead to Network-Wide Broadcast (NWB) calculation errors. A lack of robustness in NWB algorithms, not a message collision problem or loss of coverage, normally causes the errors. The researchers, therefore, reviewed gossip–based routing [55-56] as an alternative method to flooding the MANET through NWB. Gossip uses a probability format that ensures at least 90% of all nodes will receive the transmitted messages, using 25%–35% fewer messages than when flooding the network with broadcasts, as is done in NWB.

By using a combination of Delaunay Triangulation, Point Location, and Nearest Neighbor formularies, all nodes and their distances from each other can be calculated. The formula used came from MathLab, but can be complied to run as C++. Applications are available that can run this program on a handheld device or if the transmitter is a central processing unit, it can be run the formula.

1. Delaunay Triangulation: DT= DelaunaryTri (x, y, z)

2. Point Location: [SI, BC]= point location (DT, x, y, z): where DT equals points on the triangle, SI – Column vector containing the indices of the simplex for each query point. M-pts is the number m-pts of query points. BC - BC is an m-pts.-by-n-dim matrix, each row BC (i,:) represents the barycentric coordinates of DT (i,:) with respect to the enclosing simplex SI (i).
3. [PI, D]= nearestNeighbor (DT,q1(),q2(),q3()): where PI - PI is a column vector of point indices that index into the points DT.X. The length of PI is equal to the number of query points (m-pts.) D - D is a column vector of length m-pts.[57]

The above formula produced the actual triangle and the distance of the nearest neighboring node for twenty randomly seeded transceivers. The formula can be used for any number of randomly seeded nodes.

Item 2. A stationary urban format provides the most opportune situation. The sensor can be hardwired on the roof of the building that has the clearest line of sight (LoS) for the sensor. All transmissions would use the fixed wired channels currently in-place. Consequently, the possibility of overloading any of the WIMAX or WIFI channels in the metropolitan areas is alleviated. Networks are moving toward 802.16e/m metropolitan-wide WIMAX and away from WIFI. WIMAX lends itself to support ad hoc mesh networks. Cable companies in urban and some in rural areas may provide flexibility in some areas. Most cable companies must provide free educational broadcasts to schools. Additionally, they must give a certain bandwidth to the municipality for transmission of judicial trials [44]. The same principles used to transmit a covert signal within the cellular system can be used to transmit a message within the cable signal.

In a rural area where cell towers are unavailable, mobile-to-mobile transmission could be used, but the operator would have to search the horizon for passing motorized or rail traffic to on which to piggyback their signal. This method could prove too lengthy in nature and highly erratic most of the time; thus, the procedure would prove to be a drain on the battery power. LoS is very useful in rural areas in which most of the terrain is accessible and unobstructed; however, the most reliable method would be satellite as it could be used in nearly all terrains. Intelesense Technologies' InteleCell can send sensor data from manned or unmanned sensors to any designed database using open source programming and the Internet. The system will also allow the civilian health authorities to procure or partner with other Intelesense users to obtain meteorological and satellite data to provide a complete analytical picture of an area during emergency actions.

The system uses 256-bit AES encryption and is designed for harsh environments. More technical information on the InteleCell is required, as well as testing with a working sensor, before any actual determination could be made about the capability of the items and the ease of programming using the open-source programming.

The most capable and intriguing network-based system researched for this project is the Cursor-on-Target (CoT). CoT is an agnostic message system that uses a machine-to-machine language based format.[38-39,41-43,58] Extensible markup language (XML) allows cross-platform communications to occur at a level that any operating system can understand. The MITRE CORPORATION in conjunction with the Air Force developed the format. The format negates the need for quality of service under most conditions. Clusters and controller would not be necessary, and the need for manned nodes would be eliminated except in certain command-designated situations. CoT can be used with any fourth-generation application and extensible style language (XSL) to format reports from the sensor information. A numerical code in a sensor report can be shown as a color to represent the chemical, making its identification visually easier on a map. The representation can be tracked if it the hazard is being carried by the wind. Consequently, mapping now becomes dynamically expressive and informative.

6. Define Terrain and Effects of Network Deployment:

Initial discussions of terrain and effects of network deployment centered on bio-environmentalists and other personnel at fixed facilities. If the scope of the use cases had remained on constructed facilities, the implications of the terrain would have been significantly different, and the device and the transmission network would be simpler to achieve. The focus of deployment shifted from hardened facilities to variable hardened or soft sites in undetermined rural and/or urban areas anywhere within the confines of the 50 United States for public health contingencies; however, for military health and environmental use, the network must have global capabilities. Worldwide capabilities encompass all known terrains and conditions: desert, mountainous terrain, cold weather, and tropical arenas during peace and police actions.

The civilian terrain varies as much in its conditions as do the military's global conditions and terrains. The terrain encompasses the concrete mountainous terrains of New York, low hot desert conditions of Arizona, and the cold climate of Alaska. If the deployment area includes a public-safety network, of which there are two types--a Long Term Evolution (LTE) 700MHz and a Broadband 700MHz [59,60]--the transceiver could connect to one of these networks in either the urban and covered rural areas.

The 700MHz networks are to be directly connected to the police, fire department, and public health. The buildings within cities assist and hinder transmissions. Depending on the material, the attenuation can be greater (concrete 28.8 dB/m at 1 GHz) or less (glass 3.4 dB/m 1 GHz). The attenuation can be high enough to deflect the wave; thus, the wave's end point can be totally changed and may miss the collection point. The vegetation, water content within the trees, and even the different species of trees can affect the attenuation of the electromagnetic wave, based on the frequency, power, and propagation path[61]. In a city, therefore, it would be advisable to use the public-safety network, cellular network, or line-of-sight, especially when the sensor is to be a fixed site accumulator that can be mounted on a rooftop or have the transceiver dial 911 or a control center.

Literature indicates the availability for reception and reliability during clement weather should remain between 94 and 98% available with only 5% degradation in reliability when using high frequency transmissions between 11 GHz and 23 GHz. Notwithstanding, the aforementioned statistic is based on a rooftop installation with a clear view of the reception antenna. In our case, the specific variance of the operational terrain remains unknown. The general layout is rural in nature, which could cause the topographical heights to deviate from below sea level to approximately 15,000 feet above sea level, if the device is used around Mount Elbert in Colorado. An average distance between the transmitter and the antenna of the receiver would be of great assistance in figuring the minimum and maximum transmission frequencies and distances to overcome known obstacles [54,61-62].

7. **Data analysis requirement of sensor data (local vs. distant):**

The physics of data transmission analysis includes calculation of segment broadcast times, error recovery, error checking, insertion of security keys in the data stream, and the viable lengths. The history of this task was based on the initial theory of the Active Tricorder, the limitations of networking, and processing power, which is over three years ago. The concepts then were data streaming similar to video processing for every measurement of the Tricorder. The current design of the Tricorder has sufficient processing capability to locate the distance and other necessary information to evaluate the dangers of the DE illumination to the health personnel and environmental engineers.

Initially, it was assumed that no data analysis would be required at the primary transmission site or at a secondary processing site. Discussions with the Air Force determined that long-term analyses of the sensor data would occur elsewhere. On the other hand, military and public health personnel at their designated response centers would do these analyses.

If the data was transmitted to an airborne collection site, the data would have to be exported from an operational, possibly a classified, database. This poses an undetermined problem that will have to be visited by the applicable Air Force agencies at a later date.

Transmission times cannot be approximated at this time as the researchers have not been able to verify their assumptions on the minimum data field requirements that will be transmitted from the Tricorder or any other sensor in the Air Force's arsenal. The twelve fields given in Section 2 were produced from a brainstorming meeting held in New Jersey with the researchers, CADRE, and Dr. R. Preston. The image and data examples without the free-formed text generated a 348KB file, not including the headers, trailers and the IPv6 header. If all of the nodes were connected to one controller, then the cumulative file would be approximately 6.8MB. By keeping the clusters to five nodes each, the transmission packet would be reduced from one packet of approximately 6.8MB in size to four small bursts of approximately 1.7MB each. In an earlier test, a file of 70MB was reduced to 7MB. The aircraft site time is thereby reduced. The size of the file and the associate method chosen will be explored later in this report.

Error checking will be accomplished using two different methodologies within the transmission and receiving process. One method is accomplished within the signaling encoding scheme. The researches were investigating the use of the Manchester coding technique, as it can be used to synchronize the clock the receiver used with a ground receiver rather than with the airborne network. The technique also makes it easy to recognize that an error has occurred within the transmission. When an expected transmission is missed, an error has occurred. Even noise will not cover any error as a fault in the broadcast will invert two signals: the one before and the one after the expected transmission[63]. To use the error checking capabilities of this method, the modulation rate is used rather than the data rate (bits per second). The data rate, as given in Stallings, is 1/Tb and D = R/L = R/log2 M

Where

D = modulation rate, baud
R = Data rate, bps
M = number of different signal elements = 2^L
L = number of bits per signal element [63]

The second error check will be an automatic repeat request (ARQ). A decoder checks for packet sequence numbers and automatically requests a retransmission.

The data dictionary checks the character sequence that repeats itself most frequently within the file, and replaces it with a single character with which it is to represent. The process is repeated for the next longest character sequence. This process compresses the file before it is run through a compression algorithm. At the receiver's end, the file must be run through the reverse of the data dictionary. The hash codes must agree or an error has occurred. These error checks are accomplished internally based on the broadcast methodology chosen for the transmitter and will be used whether CoT is chosen or not.

8. Determine EM Footprint:

The EM footprint would be listed in the specification table for any off-the-shelf transceiver chosen to transmit the sensor data. If a system were to be designed, the precise device, power source, antenna, and test transmissions would have to be tested and calibrated to ensure the EM was correct. It is still unknown if the equipment needs to meet any Tempest requirements before it is accepted.

9. Determine the required Transmission Security Measures:

It is unknown if any of the sensors are transmitting any known electronic personal health information (ePHI) to the collection point. However, given the breadth of civilian and military research and development in sensors to record health information, it is reasonable to assume that ePHI will be transmitted in the near to foreseeable future. If ePHI is transmitted in the packets being sent back from the nodes, the transmissions will require encryption, even while the information is in transit from one node to its nearest neighbor or controller. HIPAA’s privacy and security laws require the protection of health data and specify that a risk assessment be done [64-65]. In discussions with Air Force, the researchers were notified that ePHI would not be in data transmissions in future. It is possible, on the civilian side however, that ePHI might be transmitted; therefore, the question still remains open and should be verified in future.

The Air Force will be converting from Internet Protocol version (IPv) 4 to IPv 6 beginning 2012. Consequently, it is advisable to use mobile IP (MIP) version 6 in the transceiver. MIPv6 is supposed to offer more security and address than found in MIPv4. It is not known at this time if the Air Force uses the switch setting within MIPv6 to enforce IP Security (IPSec) in the Authentication Header to enforce authentication and encrypt packets at the IP level [24].

It is also unknown at this time how the Air Force intends to handle the problem of pre-shared private (secret) keys or public keys to validate identities during the authentication process. This decision rests with Air Force's communications specialists. A hashing algorithm may be needed to produce a digital signature and a decision made as to whether NIST DSA or RSA standards will be used.

If CoT is used, security should be handled according to procedures dictated by the format and the design group working on the communication test team. IPv 6 should be used with CoT to keep within DoD's mandate to migrate to IPv6 from version 4.

Handheld

1. **Transmission of Data from Sensor to Transmitter:**

The initial proposal called for analysis of all proposed methods to transfer the data from the Active Tricorder to a transmitter, without causing the sensor to malfunction or the operation to cease during the collection period. Depending on the linking method chosen, protective measures against interference during transfer should be considered and selected. If the method to connect to the Tricorder is a wire, the wire and the connector should have an impedance of 75 ohms. The prescribed wire and connector will give the best performance for the data output during all environmental conditions. Infrared (IR) and Bluetooth could be used to connect the Tricorder to a mobile laptop or handheld transceiver within a short line-of-sight distance of 100m under excellent environmental conditions. Conversely, IR and Bluetooth transmissions, even in minimal transmittal distances, will be reflected and/or refracted during intense rain, condense fog or heavy particle movement[66]. These same conditions would also hamper the use of a directed energy device; thus, limiting the need for the Active Tricorder in the first place. As the functionality of the Tricorder evolves, additional research will be necessary to assess transmission functionality.

Current technology and the necessity for stealth movement of public health, first responders, and other personnel limit the use of Bluetooth as a wireless connector between the Active Tricorder and a transceiver. TrafficCast of Madison, Wisconsin, is using technology that captures the unique identification marker of the Bluetooth device called "Bluetooth Travel-time Origination and Destination (Blue Toad)". The company uses it to trace the devices of drivers to calculate the speed and direction of traffic on the expressways in Chicago, Illinois. This technology is commercially available, making it easy for anyone to report movement of the public health, first responders, and other key personnel in an automated way. This limits the use of Bluetooth for current and future Tricorders until the technology to cloak the identifier is developed [67].

2. **Define Data Transmittal Formats:**

The researchers had planned to use the Active Tricorder's specifications derived from the collaborators on the project to determine the logic and technique for analysis of any sensor data. The collaborators met in New Jersey on April 21, 2011, to discuss the data format [68].

The format is speculative as the Active Tricorder is in the research phase. Given the passage of time required for security clearances, the researchers had a shorter time period for access to key Air Force personnel with whom to converse. The civilian public health, homeland security, FAA, and FBI expressed interest in receiving the data, but mentioned the lack of infrastructure and funds to build the underlying foundation. Towards the end of the project, the researchers were provided a copy of the Laser Injury Guidebook. Depending on the concept of operations of the individual, if concerned with medical treatment or injury, the 30 questions from the Laser Incident Questionnaire should be added to the transmission after injury or at a later occurrence.

The data received from the sensor must be encapsulated within a header and trailer by the transceiver based on the formats used by the end user--either the Air Force or public health service. Air Force regulations have specific codes and formats based on RFC (Request for Comments) accepted by the Internet Engineering Steering Group. If the format and codes are not precise, the message/file will be rejected. Every sensor's transmitter must enclose each file in a header and trailer along with an accompanying Internet Protocol header and trailer to direct the transmission the next receiver and state how many files are in the packet. In the compression test, the researchers only combined two files together, and then ran the compression routine to simulate the field conditions. This concept will be discussed more in-depth in the compression section.

Currently, the projected sensor data raises no warning flags concerning the need for a buffering mechanism to compensate for a difference in transmission speeds, collection methodologies, or download capabilities of the sensing equipment. Technology has expanded the processing power, while shrinking the size of storage and enhancing the storage capabilities. Even the size of the transceiver boards has shrunk to 17.5 x 20 mm, and the weight of a portable computer is less than 3 pounds, depending on the functions that it must fulfill. Once the actual functionalities can be confirmed, it should be possible for Air Force personnel to use a tablet PC to accomplish the protocol processing and the transmission of required data.

3. **Determine Process to Download Sensor Data to Transmitter:**

The researchers began investigating the processes that would be necessary to download the various sensor data to the transmitters at the capture points before transmission to the designated centralized collection site and/or controlling network. This research progressed very slowly due to unclear specifications about the collection site and/or the controlling network to use as a connection for the proposed ad hoc mesh wireless network.

The determination in this report related to this scope are based on information currently known about the Active Tricorder and supplemental information from a brainstorming session mentioned previously in this report..

Data

1. **Determine the Time Sensitivity of the Data**

As stated in the initial contract, the raw output from the sensor will be driven by the detection scheme; however, the way the data are transmitted to collection sites can vary greatly. The analysis of the various types and methods of collection to be used on the network will aid in optimizing the methodologies, protocols, and devices for transmission and receipt at the collection sites. As an example, if time-sensitive data are in the information, the transmission must be successful within a determined time frame to be of use at the collection site. Furthermore, sequence sensitive data must be received as a complete packet within a certain window of time to be of value for analysis at the command and to show progression of the object of interest. Analysis of protocols selected for use must annotate the transmission sequence and require an acknowledgement from the collection sites to ensure correct and successful receipt of the data.

The MIPv6 or IPv6 header format and the subsequent header segments have pre-determined fields and codes that indicate the quality of service, routing directions by hops, use of IPSec, handle authentication, annotating the size of the packets being transmitted, etc. The IPv6 and associated sections have very explicit formats and designated codes that must be in certain fields. If the codes are not correct, data transmissions will not be accepted by other nodes; wireless network will not be recognized by their home agent; authentication to log-on to the home network and/or the collection site will be denied; and the IP security tunnel will not form [14,16-18]. The researchers firmly believe the formats for IPv6 and other pertinent protocols should be made available when necessary in future. This requirement will be moot if Cursor-on-Target is adopted. The entire packet will be compressed and enclosed within the CoT message, ensuring timely delivery with a stale time. The stale time will notify command when the message is no longer valid.

2. Determine the Optimal Data Packet:

The quantity of the data necessary to provide meaningful information to commanders will aid in determining the segment sizes, protocols, and optimal methods for transmission. If the quantity of data sent is small, a high data transmission rate that is interrupted at pre-determined intervals is realistic.

Discussions with key project personnel to resolve questions could not be scheduled. The quantity of data determines if a buffering mechanism is necessary at the broadcast site due to differences in the speed of transmission, collection, and downloads capabilities of the sensing equipment. The collection sites were not analyzed for the capability of simultaneously accepting data from multiple sites without loss of information. During the time lapse since the start of the project, technology has made the question about a buffering mechanism a moot point also. The transmitter can exist in a small rugged lightweight notebook with a transceiver card, and hold a 320 gig hard drive. There remain open questions about the timing window for receipt of the data from initial incidence to final acknowledgement. The information determines cutoff of collection and the start of transmission. The operator of the cluster controller can send out multicast to all nodes, or a protocol can be built to accomplish the same object with a function key input.

The researchers recommend CoT using User Datagram Protocol (UDP) with multi-cast to reach multiple command sites carrying no more than a 100kb packet. If the plan is to use fast movers, the size of the packet should be scaled down to approximately 40 bytes and Transports Control Protocol (TCP). These estimations require testing to be accurate.

3. Compression:

The data packet size from a node is unknown. The type of sensor that will be part of the sensor and transmitter pair will be unspecific until transmission time; the packet could be a chemical sample, DE, or soil core test. A global positioning system reading, free text from program function or a formula generation could accompany any of the sensor's data. Given all these unknowns, the researchers investigated various compression routines that could handle images, numeric, alpha, and special characters. The investigation covered Fourier transforms and Lempel-Ziv-Markov chain Algorithm (LZMA). The Fourier transforms is an excellent compressor if the data types are already known, and the correct equation can be tested. The test is to ensure equation with the closest frequency domain will reproduce the image correctly when decoded. Fourier Image compression would allow for better compression, utilizing wavelet compression and transmission; however, the compression methodology contains some looseness or uncertainty. This uncertainty is due to the time and frequency domains being complementary, thus, not allowing an exact time/position representation of a given point or pixel in space, called the uncertainty principle [69]. The post-compressed image, therefore, is not an exact copy of the pre-copy, based on a pixel-by-pixel representation. The same misrepresentation can affect the compression of text if the incorrect transformation is chosen.

There are two distinctive types of compressions mention in literature, Lossless and Lossy. Lossless compression allows the decoder to be an exact duplicate of the original input file. The Lossy compression method permits the output to be altered from the input, with the user accepting the product difference. This is normally occurring in images and audio decoding [70, 71].

LZMA is the default compression algorithm in 7-zip, sometimes called 7-z. A free development kit with the LZMA source code is available to modify the code in C, C+, C++, or Java. It can encrypt the compressed data using AES-256. Seven-z also has five other compressors in the algorithm that can be used[69]. Seven-zip was tested during the project using mock data based on the 12 elements given above. The software compressed the file from approximately 7MB to 7 KB, then decoded the zip file without losing any image detail. A free development kit comes with the LZMA source code. The importance of the location, power, and wavelength of DE makes it imperative that Lossless compression be used, thus, 7-zip is recommended.

Determine Additional Requirements:

Additional inputs from field users could add value to the sensor data; for example, time stamps, GPS coordinates, and orientation of the sensor could be appended to sensor data to enhance awareness and to provide more precise medical records. The collection of the additional inputs from the Laser Incident Questionnaire or others, their connection with sensor data, and possible effects on the overall network interaction should be studied.

The researchers only had information covering the Active Tricorder. The recorder captures an image, GPS, time, and DE information. The compression test included those fields, longitude and latitude of the DE lighter, Zulu time (Active Tricorder time in Zulu), and GMT designator for health personnel unfriendly. It would have been more advantageous to have the end user provide the parameters that they require to meet their tasking. On the other hand, if Cursor-on-Target is chosen as the transport method, its ability to converse machine-to-machine with any system, whether it is non-proprietary or not almost making the need for these items a mote point. Information can be shared using different small applications to translate information from distinctive systems in the general area. The information then can be promulgated to other systems making it easy to share time, geo-location, and system data.

4. Results and Discussions

Results

The researchers completed the investigation into a reliable network system to transmit sensor data to various collection sites without having all the constraints or concrete requirements specified. To overcome the unknown transmittal distance from broadcasting area to collection point, the system can use the extensible markup language (XML) to traverse the urban areas to arrive at a designated public health and safety department [39]. If the sensor is close to a public-safety network system in a rural county, the transmitter can use the Long Term Evolution (LTE) 700 MHz or the Broadband 700MHZ to enable connection through 911 to send data [45, 59, 60]. An application can also have the transmitter search for a cell tower. If a tower is found, the sensor information can be sent covertly, mixed in with other transmissions [44].

The users never defined the types or quantity of data collection points for the Active Tricorder or the quantity of revised requirement to handle any type of sensor data. Consequently, the project was completed using mock data sets. The simulated data sets allowed the researchers to test data compression theories, but this only represents the researchers' view of the data from Active Tricorder, which was still under development. If Cursor-on-Target (CoT) is chosen as the transport medium, the actual data type will not matter. The information could be compressed and contained in the free text field of the message format. Consequently, the transport is more adaptable and easier to maintain within a deployable inventory.

No single network has been designated as the primary system; many programs exist under many different names. RAIN (Remote Access Internet), which is under the ISR Innovation team, uses airborne Internet Protocol (IP) and interlaced networking similar to CoT. Additionally, the Airborne Network Layer is still viable and being used with the different Air Force command structures. Cursor-on-Target is an agnostic IP machine-to-machine language based transport format that can work with either Rain or the Airborne Network Layer system. CoT can function under the conditions that either the broadcaster has a portal to the Internet or any other transmitter or machine is in the area to act as a repeater. Of course, the transmitter must contain an application to format the XML format correctly. CoT makes quality of service a moot point as each message will travel individually over the Internet. Provisions within the format are possible to ensure certain messages receive priority over other types of transmissions.

The cluster configuration, with or without gaming and robot theory, can be used with CoT. When used with movement, especially during chemical sampling, it would enhance the overall progression continuity picture for command assessments and actions. The Delaunay Triangulation used with Point Location and nearest neighbor equations will identify the points of randomly seeded transceivers from each other. The formulary can be used when global positioning system information is not available.

No buffering system will be needed, especially if CoT is adopted, and the information is transmitted as soon as it is received from the sensor. If the information is in numerical format, it can be compressed and shipped within the free format field of the XML format of Cot. Extensible style language or a fourth generation language can reformat the data for reports at the command site.

Discussion

The project for the Networking and Informatics group was to investigate and locate an all-weather, secure, wireless technique through a literature research to transmit information from the Active Tricorder to all identified public or military agencies. The data was to be transferred from the point of collection to an assigned host or network with end points announced at a later date. The data transfer was not occur in a practical and undetectable manner to any given interim or final collection point without regard for the area surrounding the designated transfer or end point. The host or designated receiving network was to be able to re-transmit the data to all identified public health or military agencies using the appropriate semantics to accomplish reinterpretation. Before the commencement of the project, no networking configuration to support the Active Tricorder or the reporting of directed energy (DE) data to public health agencies and meeting the Air Force's requirements were known to exist.

The preliminary findings provide a foundation to the Air Force from which to build future inquiry, both for military and non military use. The findings from agencies that may track internally and/or use DE incident data for publication indicated no one except the Federal Aviation Agency (FAA), Food and Drug Administration (FDA), and the Federal Bureau of Investigation (FBI) had DE data. FAA kept on paper the aircraft-related incidence information collected by pilots at specific times. Attempts were made to contact the FBI's National Crime Information Center (NCIC) to discern what direct energy (laser incident) information is stored in their database. A message was left for Chief Analyst of the design team in Washington D.C., with no call back.

During an Airborne Network conference in Arlington, Virginia, 14-15 October, 2010, Colonel Lenertz, CTR USAF ACC AFC2IC/RIN, emphasized the requirement to have a network controller to monitor and control the transmissions, manage fault recovery, and define rules (protocols) to communicate between the nodes within any network [36,72]. The flying layer has limited collection time based on fast movers collecting data; dark communication areas due to an aircraft's orbit or glide over a path diminish the line-of-sight transmission/receipt time. Consequently, errors and re-transmission must be marginalized at all cost. This action can be accomplished through network management, enforced by manned or unmanned controllers that supervise the network and/or node transmissions and network error recovery. The requirement for each network to have a designated network controller to manage manned or remote-controlled networks in the air or on the ground is an Air Force wide mandate or will be shortly. This mandate will necessitate the use of clusters with cluster heads configured as controllers or manned by health personnel. If the clusters are unmanned, each node will have to be constructed through program monitoring to become the cluster head if the main controller fails. Cursor-on-Target negates the requirement for a controller. Each node can be on its own, with the transmission using the CoT router [41] for guidance. The Internet Protocol format of CoT would allow the packet to be lead to the final destination in a secure manner. CoT can also give the SGR the capability to integrate future applications with current programs. Cursor-on-Target provides a method to combine information from different proprietary and open source systems to update intra and extra-command program.

Joint Forces Command used CoT to integrate information from four different unmanned aerial vehicles (UAV) and display the data on a single manned display. The operator could input target information that would feed back to all the UAVs simultaneously. CoT enabled the Command to enhance the performance of the UAV to focus on coding with XML [42]. This capability would give the SGR eminent flexibility now and in future. The translation programs could be small XML or fourth-generation programs that run on the iPhones.

Another consideration is the ability of the extensible markup language (XML) to allow non-proprietary and open source systems to communicate interoperably. Interoperability also enhances the performance and communication of inter-command operation. The North Atlantic Treaty Organization (NATO) developed a strategy for their blue force tracking system based on the Web-services using extensible markup language (XML) standards. NATO Consultation, Command and Control Agency General Manager, Dag Wilhelmsen stated XML provides a platform for the sharing of data between nine different nations [40].

In the civilian health responses arena, a briefing given on covert communications at MILCOM 2010 in San Jose, California, confirmed that cellular lines could be used to send data. The information could be sent directly from sensors to a collection point in or around a rural or urban area in a clandestine manner [44].

Additionally, a world patent provides a method that would force the telephonic system to dial the 911 center and provide data; a predetermined signal notifying the center to be ready to accept data or send telemedicine information to a hospital [45]. These methodologies, however, are not available to the civilian public health agencies, although, many are interested in receiving the data or processed information on directed energy (DE). They do not have the funds necessary to build storage or receiving system.

Inter-agency talks between Homeland Security, Public Health, Centers for Disease Control, Air Force Surgeon General, and Federal Aviation Agency might facilitate an alliance to determine a way to get the needs of all participants reflected in one national database that could be portioned in secured sections and shared. These actions would assist in research, especially in determining the data that are needed to produce the information to secure the health and welfare of the nation, whether from internal or external actions, without unnecessary duplication of effort. The basic foundation of this project was to be able to transmit necessary and valuable DE and sensor data from the sensor transmission area.

The area may be located anywhere within the rural or urban confines of the 50 United States or the tactically operational areas of military health units to collection points to be designated within the given boundaries. The focus of this research was the Active Tricorder. The Tricorder is still under development, and its output data is an image, exposure information, time, and GPS; it does not estimate the GPS location of the DE lighter. If the information is to be of value, the commander or public health environmentalist will need to know the exact, or a very good approximation of, the location. The time could be inserted into the transmittal field, based on the assumption that it would be required for most sensor files; it would be the time of the sensor recording because the transmission time is recorded in the Internet Protocol header segment [9, 10]. Key Air Force personnel must clarify those areas of contention to provide the direction essential to the mission and the project in future endeavors. The sensor data fields the researchers believe the fundamental minimums can be found in Section 2.

The researchers first assumed the project was to meet the standards for privacy and security put forth in the Health Insurance Portability and Accountability Act, Final Privacy and Security policies. It remains unknown if the medium access control (MAC) is used to identify nodes during transmission or whether the transmission should be encrypted or not. All of these questions must be answered by the Air Force in future as they build protocols. If CoT is adopted as the transport foundation, the privacy and security policies accepted under XML format and CoT schema will be followed rather than medium access control currently in use. The format agreed to in the building phase will become the dominant format.

5. Conclusions

The research team recommends use of Cursor-on-Target as the transport foundation for an 802.11n ad hoc mesh network, using 802.11x, e, s, and i protocols. The transceiver should be capable of transmitting and receiving UMTS/HSPA/HSPA+/DC-HSDPA/GSM/EDGE/LTE 700, 850, 900, 1900, and 2100 MHZ. It must have a dual-core processor, a minimum 64-gig with 802.11 g/n and Bluetooth 4.0 capability along an Internet connection. The researchers strongly recommend that the Mil Std. 2525B symbolic hierarchy be built in conjunction with other health services, enhancing the interoperability for communications during joint operations.

U.S. Joint Forces Command and NATO have come to accept the flexibility and the need to share information and a communications foundation that will allow machine-to-machine conversations. Network communications can use a smaller portion of bandwidth while moving more data to multiple sites in a more efficient and effective manner. Cursor-on-Target allows proprietary systems to share data and update systems with machine speed and accuracy. It can reduce the requirement to use four displays down to one display, while updating concurrently commanders at multiple locations [12,38-43,72].

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7. Appendix

Figure 2

Figure 2: Active Tricorder Image

Equations

Equation 1 Locate Boundary Nodes

The actual formula format is –

```
rand('seed',0);
q1=rand(20,1);
q2=rand(20,1);
q3=rand(20,1);
x=20*rand(20,1);
y=20*rand(20,1);
z=20*rand(20,1);
k=rand(20,1);
for j=1:20
DT=DelaunayTri(x,y,z)
[SI,BC]=pointLocation(DT,x,y,z)
[PI,D]=nearestNeighbor(DT,q1(),q2(),q3())
kj=D
end
```

8. List of Symbols, Abbreviations & Acronyms

Symbols

°	Degrees latitude or longitude
‘	Minute in latitude or longitude
“	Seconds latitude or longitude
DT = Delaunay Tri (x, y, z)	x, y, z create a Delaunay triangulation from a set of points. The points can be specified as column vectors (x, y, z) for 3-D inputs.
SI	Column vector of m-pts. containing the indices of the simplex for each query point. Mpts is number of query points.
BC	Barycentric coordinate is a m-pts-by-ndim matrix, each row BC(i, :) represents the barycentric coordinates of QX, written x in our formula, with respect to the enclosing simplex SI(i).
q1	Matrix of size m-pts-by-ndim for (x)
q2	Matrix of size m-pts-by-ndim for (y)
q3	Matrix of size m-pts-by-ndim for (z)
(PI, D) = nearestNeighbor	Returns index of nearest point in DT. D is a column vector of length mpts.
%	Percentage
T_b	Duration of one bit
D	Modulation rate, baud
R	Data rate, bits per second
L	Number of bits per signal elements
$\log_2$	Log of 2
$M = (2^L)$	Number of different signal element

Abbreviations

AES	Advance Encryption Standard
ARQ	Automatic Repeat Request
CoT	Cursor-on-Target
DCHSDPA	Dual-Cell High Speed Downlink Access
ePHI	Electronic Protected Health Information
FAA	Federal Aviation Administration
FDA	Federal Drug Administration
FBI	Federal Bureau of Investigation
GCIC	Global Cyberspace Integration Center
GHz	Giga Hertz
GIG	Global Information Grid
GPS	Global Positioning System
GSM	Global System for Mobil
HSPA	High Speed Packet Access
HSPA+	High Speed Packet Access Evolved
IP	Internet Protocol
IPv	Internet Protocol version
ISR	Intelligence, Surveillance and Reconnaissance
KB	Kilobytes
LoS	Line of Sight
LTE	Long Term Evolution
LZMA	Lempel-Ziv-Markov chain algorithm
MB	Megabyte
MIP	Mobile Internet Protocol
NCIC	National Crime Information Center

NWB	Network Wide Broadcast
QoS	Quality of Service
RSA	Rivest-Shamir-Adleman
RFC	Request for Comments
TCP	Transport Control Protocol
UAV	Unmanned Aerial Vehicle
UDP	User Datagram Protocol
UMTS	Universal Mobile Telecommunication System
XML	Extensible Markup Language
XSL	Extensible Style Language

Acronyms

CADRE	Center for Advance Design, Research and Exploration
DE	Directed Energy
DSA	Digital Signature Algorithm
HIPPA	Health Insurance Portability & Accountability Act
IPSEC	Internet Protocol Security
LEACH	Low Energy Adaptive Clustering Hierarchy
MAC	Medium/Media Access Control
MANET	Mobile ad-hoc network
MIMO	Multiple-in Multiple-out
MITOC	Man-Portable Interoperable Tactical Operations Center
NATO	North Atlantic Treaty Organization
NIST	National Institute of Standards and Technology
QoS	Quality of Service
RAIN	Remote Access Internet Protocol